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Seasonal Changes in Radiometric Temperature of Rice Vegetative Cover

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Abstract. Thermal infrared radiometry is a reliable technique for measuring temperature of vegetative cover. Vegetation (canopy) temperature can be incorporated into a crop growth model to evaluate soil moisture availability, leaf water potential, and plant water status. Field experiments were conducted to monitor and analyze seasonal changes in radiometric temperature of rice vegetative cover during cropping seasons of 1996-1998 in Taiwan, using the technique of thermal infrared imagery. Distribution of canopy temperature fluctuated with climatic conditions and also varied during growing periods, indicating that geometric structure and pigment composition changes as plants develop. Difference between maximum and minimum canopy temperatures was increased as plants aged, implying again an alteration of canopy structure and coloration with plant development. Further, canopy temperatures were lower than ambient temperatures throughout growth phases in both crops. Canopy temperature was positive correlated (R^2 = 0.6275) with ambient air temperature in the range of 22-36°C. Results indicate that rice maintains an effective heat-dissipating process (transpiration) under well-watered conditions, and the capacity was altered by changes of air temperature up to about 36°C. Extensive thermal infrared image observation over vegetative cover of rice crops have allowed the evaluation of the infrared remote-sensing method in radiometric temperature measurements.

Key words: Seasonal change, Radiometric temperature, Canopy temperature, Vegetative cover, Rice.

水稻植被輻射溫度之季節變化

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摘要：熱紅線輻射測定爲現代遙測科技之一，由於具有即時、非破壞與高準確度等特性，近年來已廣泛應用於農作物生產作業系統。除了作物植被溫度之快速偵（檢）測，

亦可結合於作物生長模式之中，以估測土壤有效水分、葉片水分潛勢、及植體水分狀態。本研究乃利用熱紅外線輻射影像技術追踪及分析不同期作水稻(*Oryza sativa* L. cv. Tainung 67)植被溫度之變化，探討植被溫度與周遭氣溫之關係。根據兩年四期作田間試驗結果，發現植被溫度受到周遭氣象環境之影響，且隨著生育進展而異，驗證了植被幾何構造及色素因植齡增進而改變的事實。又由植被最高溫與最低溫之差異隨著植體發育而增加的趨勢，再佐證了植被結構及色澤隨生育而複雜化的現象。在本試驗栽植期間，植被溫度均低於周遭氣溫，且呈現正相關(R^2 = 0.6275)。換言之，在氣溫22–36°C範圍內，水稻植體均能視氣溫之變化適時調整體溫，顯示了在田間正常蓄水狀態下，稻株維持散熱功能（蒸散作用），而此一調適能力至少持續至氣溫36°C。結果也顯示，熱紅外線輻射遙測技術提供了一條觀測作物植被溫度變化的途徑，利用為改善作物栽培環境（凡引起植被溫度變化之環境因子）之有效工具。

關鍵語：季節變化、輻射溫度、植冠溫度、植被覆蓋、水稻

INTRODUCTION

Water supply and temperature are two primary environmental constraints for plant growth (Kanemasu *et al.*, 1985). The effects of these factors are difficult to separate because of their strong conjugation in mechanisms and reactions involved. Thermal infrared remote sensing is a promising technique in temperature measurement and can serve as a means to measure and monitor seasonal changes in temperature of a vegetative (canopy) cover during the growth of crops both conveniently and effectively. The technique provides information on the water status of plant vegetation and its correlation with ambient air temperature nondestructively and nondisruptively. By radiometric temperature measurements, heat transfers between soil, vegetation and atmosphere are connected, and the physiological functions of crop (canopy) evapotranspiration and vegetation vapor resistance are inferred (Taconet *et al.*, 1995). Measurement of infrared surface temperatures, together with meteorological data, can also be applied to estimate the surface energy balance (Kustas, 1990; Seguin and Itier, 1983) and the water regulation of plant transpiration through the stomata (Taconet *et al.*, 1995).

Within a plant population, it is the vegetative cover that intercepts radiation incident upon them. In most plants, such as rice, leaves are the major organs for intercepting sunlight in the field. Monitoring of radiometric temperature of vegetative cover is critical to the determination of plant water status for better water and crop management throughout the season (Throssell *et al.*, 1987). Air temperature affects heat dissipating processes of a plant, and hence, the actual canopy temperature which governs photosynthesis and other plant growth functions, is also crucial, and can be applied to irrigation timing and stress level determination. Incorporation of thermal infrared remote sensing into a crop breeding program would be valuable and practical for large-scale screening drought resistence/avoidance germplasm in the field (Blum *et al.*, 1982; Chaudhuri *et al.*, 1986; Garrity and O'Toole, 1995; Hatfield *et al.*, 1987; Kirkham *et al.*, 1984; Mtui *et al.*, 1981; Singh and Kanemasu, 1983). From infrared readings reported in the literature, different canopy temperature indices have been developed to quantify water deficit (Clawson and Blad, 1982; Gardner *et al.*, 1981; Idso *et al.*, 1977) and to aid in classifying crop cultivars for relative drought avoidance (Garrity and O'Toole, 1995).

In this paper, investigation has been focused on monitoring seasonal changes in radiometric temperature of vegetative cover and determining ranges of temperature fluctuations in different

cropping seasons of rice, using the technique of thermal infrared imagery. Attention has also been placed on analyzing the relationship between canopy (vegetation) temperature and air temperature during the growth of rice in the first and the second cropping seasons.

Materials and Methods

Field experiments were conducted at the Taiwan Agricultural Research Institute (TARI) Experimetal Farm (24°02'N, 120°42'E, and elevation of 85 m), Wufeng, Taiwan. Rice (*Oryza sativa* L. cv. Tainung 67) was grown on a loam soil (nonacid, hyperthermic, Fluvaquentic Dystrochrept) of pH 5.30 at a density of 22 plants m^{-2}, row spacings of 0.3 m and plant distance of 0.15 m, from 2 February to 10 July 1996 and 2 February to 19 June 1998 for the first crops, and from 5 August to 18 November 1996 and 31 July to 25 November 1997 for the second crops, respectively. Each crop had 3 replications in the field with plot size of 18 m length by 11 m width. The 2 (2nd crop) to 3 (1st crop) weeks old seedlings were transplanted in north-south rows, and were replanted 3-6 days later for the uniformity.

Fertilizer Taifei-39 (granule, $N:P_2O_5:K_2O$ = 12%:18%:12%, Taiwan Fertilizer Company, Kaohsiung, Taiwan) was applied at transplanting at a rate of 400 kg ha^{-1} as a basal dose and additional ammonium sulphate (21% granule, TFC) was added at 4 weeks after transplanting at 400 kg ha^{-1}. Urea (46% granule, TFC) at a rate of 400 kg ha^{-1} was applied 1 to 2 weeks before heading. Herbicide butachlor-benthiocarb 8% granule [5%, S-(4-chlorobenzyl)-N,N-diethylthiocarbamate; 3%, 2-chloro-2',6-diethyl-N-(butoxymethyl)acetanilide] was applied in 1996 and butachlor-CNP 8% granule [3%, S-(4-chlorobenzyl)-N,N-diethythiocarbamate; 5%, 2,4,6-trichlorophenyl-4-nitrophenylether] was applied in 1997, respectively, at 30 kg ha^{-1} within the week of transplanting. Hand-weeding was also practiced at 4 weeks after transplanting. Triphenyltin acetate (2% granule, 15-20 kg ha^{-1}) was applied after transplanting once for pest control.

Thermal infrared images of rice vegetative cover were remotely taken, as described in the followings, near midday (11:00-12:00, local standard time) on clear days, to minimize solar angle interaction with the viewing direction (Garrity and O'Toole, 1995), using a thermal infrared (IR) imaging radiometer (8-12 μm, model 760, Inframetrics Inc., Massachusetts, USA) within a 10.5 m^2 spot (window). The IR imaging radiometer was held at an oblique angle (ca. 30°) to the vegetative (canopy) cover to minimize the influence of the soil (Kanemasu *et al.*, 1985). The distance to the spot center from the instrument was ca. 5 m. The system contains a scanner with 1X standard lens, a fiber-optic cable connecting to a main controller, and a 12-V rechargeable battery. The scanner has a 15° vertical field-of-view and 20° horizontal field-of-view. The emissivity of rice vegetation was assigned at 0.98, the external optics transmission was fixed at 1, temperature range was adjusted to 10°C, and the background temperature was measured and set at the time of measurements. The radiometer calibration, −20 to 400°C Normal Range, was performed at the laboratory of Inframetrics with reference black bodies. Thermal data were analyzed and transformed to radiometric temperature using ThermaGRAM software (Thermoteknix System Ltd., Cambridge, England) specific for Inframetrics model 760.

In the early stage of growth, thermal images were analyzed by points and windows (picture areas) for dense vegetation to determine canopy temperature (Tc). Three thermal images were taken from different directions per plot periodically and the radiometric temperatures of the images (windows) were averaged, mean, maximum and minimum values of 3 replicates were computed and reported. Vegetative cover was considered dense when the covering percentage was 70% and above, about 40 and 30 days after transplanting for the

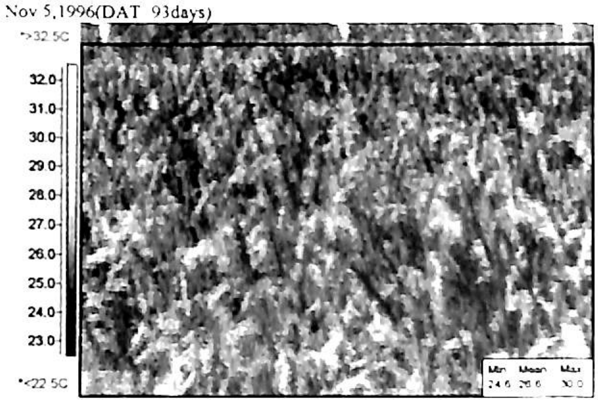
first and the second crops, respectively. Percent vegetative cover was determined by a grid method. Three slides of a near 10 m^2 area of paddy were taken from each plot and projected onto a sheet of paper with 20 × 20 grids (3 cm-grid). Covering percentage was computed by dividing the number of intersected counts over the total grids.

Ambient air temperature (Ta) was measured by a covered and natural wind-aspirated hygrometer (Model A2, Rotronic Ag Inc., Swiss) 1.5 m above the ground. Wind speeds were less than 4 m s^{-1} during the measurement periods. Regression analysis was employed to evaluate relationships between canopy (vegetation) temperature and ambient air temperature.

Results and Discussion

The thermal IR image taken on 5 November 1996 is shown in Fig. 1, as a typical example of radiometric temperature measurement. Within the set range of 22.5 to 32.5°C, variation of canopy (vegetation) temperature anywhere in the displaying screen can be revealed and analyzed as needed. Frequency analysis was used to calculate temperature distribution of the fixed (rectangle) area of canopy in the image (window). More than 93% of vegetative cover had temperatures lower than the ambient temperature (27.6°C) with the mean, minimum, and maximum at 26.6, 24.6, and 30.0°C, respectively. Radiometric temperatures within the vegetative cover fluctuated from 24.6 to 30.0°C, a 5.4°C gradient. Garrity and O'Toole (1995) reported that, at midday, solar radiation and wind speed fluctuated extensively and influenced canopy temperature significantly. Accordingly, the thermal IR image measurements provide a good estimation of canopy radiometric temperature over the life cycle of rice, as plotted in Fig. 2 in a 3-D fashion.

Fig. 2 indicates that distribution of canopy temperature fluctuated with climatic conditions, and varied during growing periods. In additional to geometric structure and color changes as plants



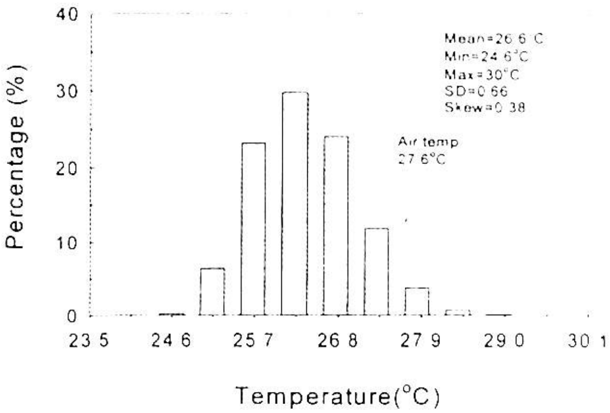


Fig. 1. Thermogram of rice (*Oryza sativa* L. cv. Tainung 67) canopy measured at 5 November 1996 and the distribution of canopy temperature by frequency analysis.

develop, it is not surprising to have diversified patterns of canopy temperature distribution in different seasons. In the previous report (Su and Yang, 1998), canopy temperatures were centered near the means at tillering and panicle formation stages but were scattered (a greater variation) during the maturing stage in both crops of 1996. The greater contrast of thermal images resulted from a higher temperature of panicles than that of flag leaves. Similar results were evident in the cropping seasons of 1997 and 1998.

Fig. 3A further showed that the maximum temperature of the rice canopy increased with the increasing ambient air temperature in the first crops, whereas Fig. 3B showed that the minimum temperature was decreased with the cooling of the ambient air toward winter in the second crops. As

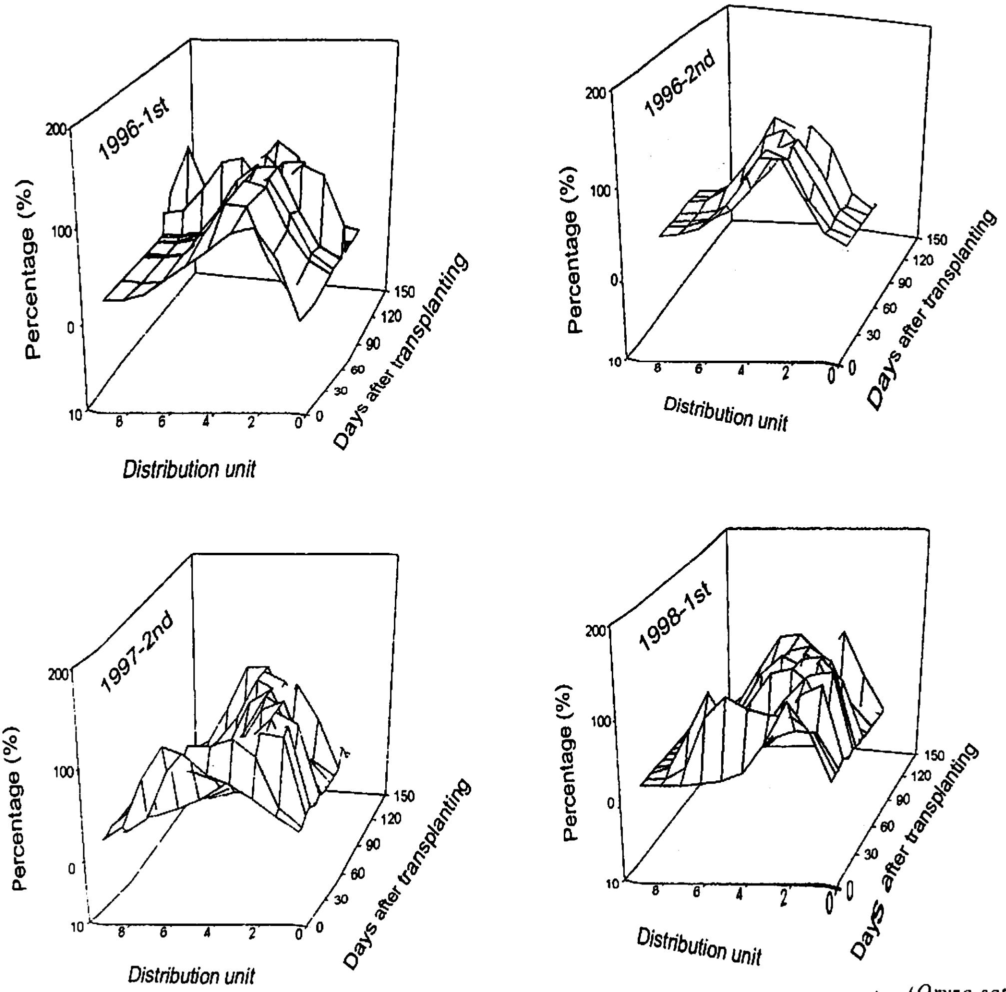


Fig. 2. Three-dimensional pattern of seasonal changes in radiometric temperature distribution in rice (*Oryza sativa* L. cv. Tainung 67) canopy (vegetation) during 1996-1998.

a result, temperature difference between the maximum and the minimum were increased as plants aged. This implies an alteration of canopy structure and coloration with plant development similar to visual observations, and therefore, results in a heterogeneous vegetative cover and greater temperature fluctuation. A mixture of leaves, tillers, and panicles creates a complicated and colorful plant appearance in developing plants.

Canopy temperatures were lower than ambient temperatures throughout the growth phases in both crops (Fig. 4). Canopy temperature (Tc) was positive correlated (R^2 = 0.6275) with ambient air temperature (Ta) (in the range of 22-36°C). This indicates that rice maintains an effective heat-dissipating process (transpiration) under well-watered conditions, and that this capacity was altered by changes in air temperature up to about 36°C. As Su and Yang (1998) pointed out, rice is able to adjust transpiration rate to ameliorate temperature fluctuation in the surroundings to a certain level for maintaining

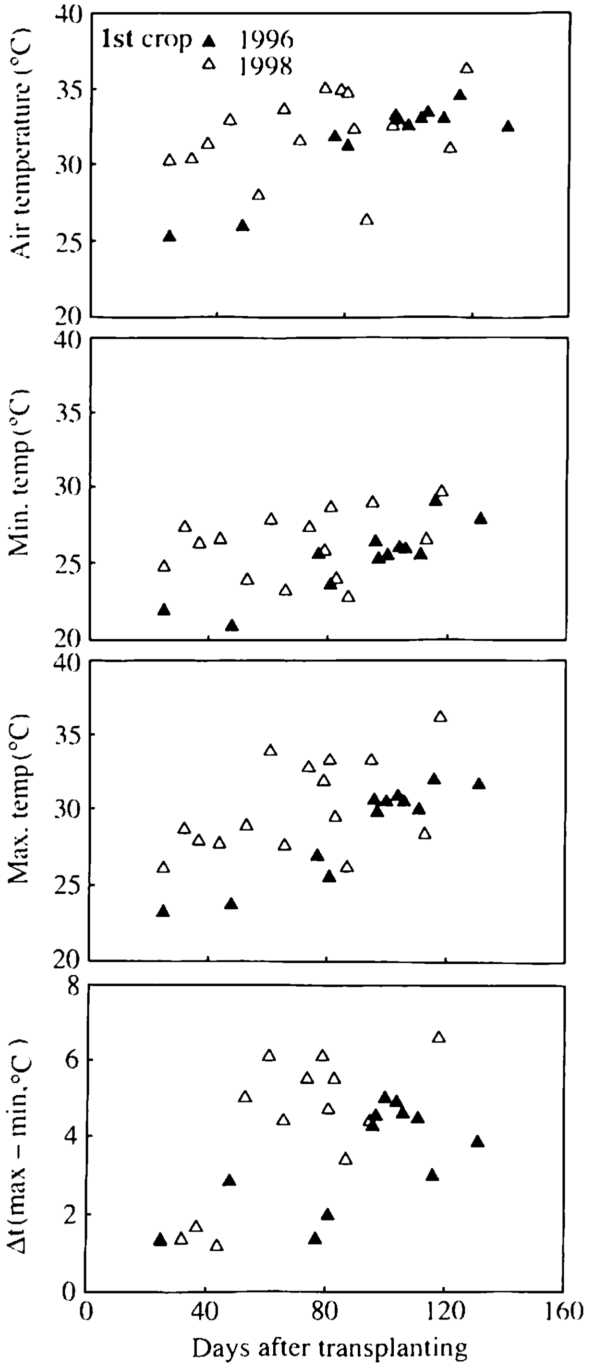


Fig. 3A. Relationship of ambient air temperature and the minimum and the maximum canopy temperatures during growing periods of rice (*Oryza sativa* L. cv. Tainung 67) in the first crops.

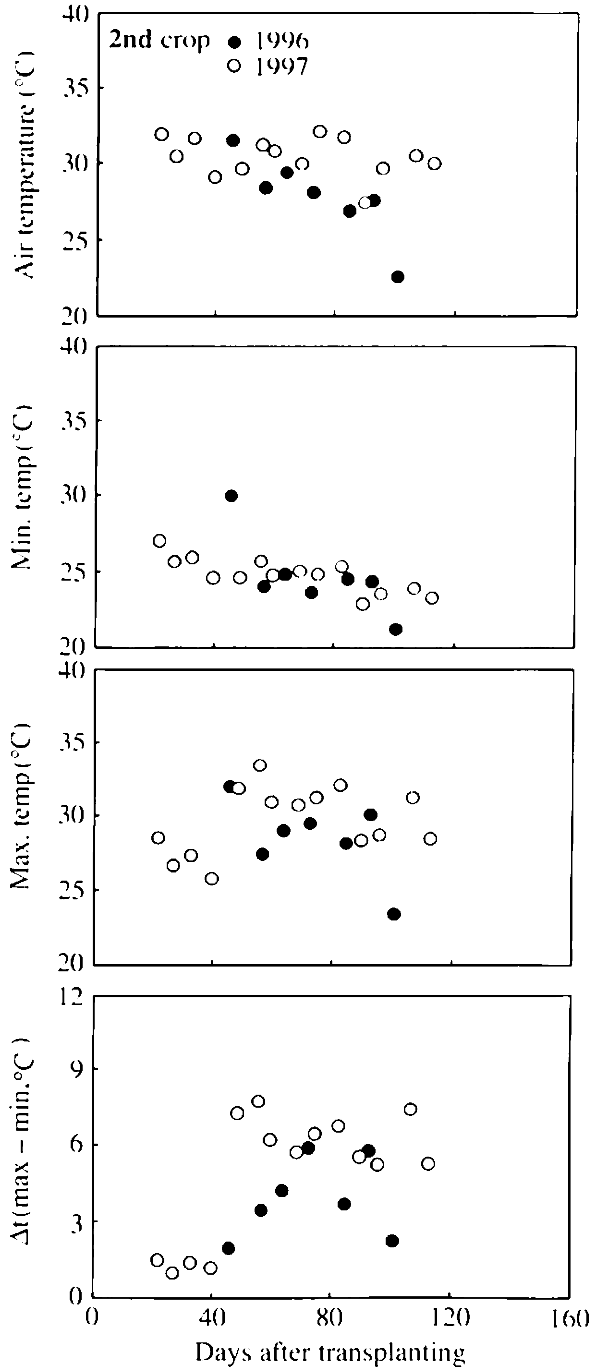


Fig. 3B. Relationship of ambient air temperature and the minimum and the maximum canopy temperatures during the growing periods of rice (*Oryza sativa* L. cv. Tainung 67) in the second crops.

normal physiological functions.

In well-watered crops, this relationship is affected mainly by vapor pressure deficit (VPD) of the surroundings, over a large range of vapor pressure, net radiation, and windspeeds (Idso *et al.*, 1981). Since a modest amount of scatter was found between first and second crops, it appears that different crops may have different

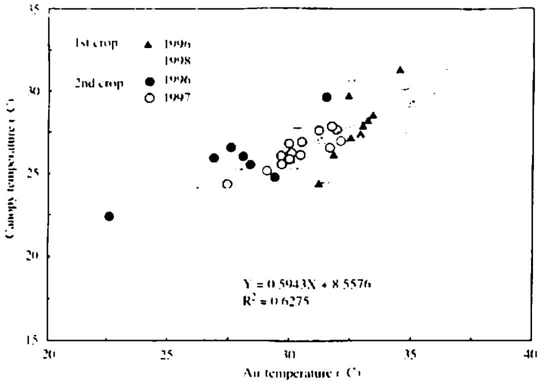


Fig. 4. Relationship between canopy temperature and ambient air temperature in rice (*Oryza sativa* L. cv. Tainung 67) vegetation grown in 1996-1998.

relationships and need to be studied further. Under water stress, the relationships will be changed for a given VPD (Kanemasu *et al.*, 1985). Thus, a continuous daily monitoring of the crop temperature could provide information as to the onset of stress and a quantitative estimate of soil moisture content. Taconet *et al.* (1995) incorporated an infrared remote-sensing method into a soil-vegetation-atmosphere transfer model so as to estimate canopy evapotranspiration on a daily scale and leaf stomatal conductance at the time of infrared measurements. Both quantities can be used to monitor water use efficiency and productivity of natural and agricultural ecosystems. The infrared thermal data can also be linked with vegetation index (Baret and Guyot, 1991; Prevot *et al.*, 1993) and be further applied in correcting or calibrating crop growth models (Bouman, 1991; Delecolle *et al.*, 1992).

As water deficits occur, stomates partially close causing a reduced transpiration, and allowing sunlit leaves to become warmer (Jackson *et al.*, 1981). Kanemasu *et al.* (1985) found that canopy temperature of spring wheat (*Triticum aestivum* L.) was usually 2 to 3° below that of the air under well-watered conditions, and that an increase in canopy temperature can be used to quantify levels of water deficiency. They concluded that canopy temperature offers a means of assessing critical water deficits. Garrity and O'Toole (1995) also indicated that differences in canopy temperature among crop cultivars were related to drought avoidance characters. Therefore, canopy temperature can be used to rapidly monitor the general progression of crop water stress development in the field.

Extensive thermal infrared image observations over vegetative cover of rice crops has allowed the evaluation of the infrared remote-sensing method in radiometric temperature measurements. By infrared thermometry, canopy temperature can be measured rapidly, nondestructively and nondisruptively. It is efficiently in providing a direct estimation of the thermal condition of canopy cover and an indirect assessment of the water status of crop vegetation. From the measurements of evapotranspiration and vapor resistance of vegetation surface can also be inferred. However, one should be careful in proper application of the technique and in operation of the instrument as well as interpretation of the experimental data. Canopy temperature has limitations in interpretation as a lone character (Garrity and O'Toole, 1995) and knowledge of the microclimate is necessary to avoid its misuse (O'Toole and Real, 1984).

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